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Honolulu, Hawaii

EFFECTS OF CARBON DIOXIDE ON QUALITY AND SHELF LIFE OF PAPAYA†

by

Ernest K. Akamine ‡

Carbon dioxide is employed to some extent in the storage and shipment of fruits elsewhere. It effectively controlled storage scald in certain varieties of apples *(4, 14, 15, 16, 22)* and in Bartlett pears *(16)*. It is also employed in the controlled atmosphere storage of apples *(13, 20, 21)*.

Carbon dioxide is further used to supplement standard refrigeration in the shipment of fresh commodities by refrigerated cars from the West Coast to the East Coast in the mainland United States. For this purpose dry ice is employed as the source of carbon dioxide *(5, 7, 11, 12, 16, 17, 18, 19)*.

Carbon dioxide in refrigerator cars is claimed to be effective in reducing and retarding development of storage diseases of certain fruits and vegetables *(7, 8)*. Initial exposure to this gas seemed to reduce growth of microorganisms in subsequent storage in air *(10)*.

In view of the apparent advantages in the use of carbon dioxide in the shipment of fresh commodities, interest was created locally in the possible use of this gas for the shipment of Hawaiian commodities. In this report, the feasibility of employing dry ice for the shipment of fresh papayas to the mainland United States from Hawaii was determined.

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* Formerly known as *Progress Notes*.

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METHODS

Freshly harvested fruits varying in stages of color development from color turning to fully colored were used in the experiments. The number of fruits employed in each treatment varied from 20 to 35, weighing approximately 22 to 39 pounds, respectively. Nearly 2½ tons of fruit were employed.

Fruits subjected to fumigation required for export fruit *(3, 9)* and hot water dip to control storage decay *(1, 2, 6)*, and fruits subjected to both the fumigation and hot water treatment were used in addition to untreated fruits. The fumigation treatment consisted of exposure of the fruits to ethylene dibromide at a dosage of ½ pound per 1,000 cubic feet of space for 2 hours at room temperature. The dip treatment consisted of submerging the fruits in hot water maintained at a temperature of 120° F. for 20 minutes. The dip preceded the fumigation whenever the same fruits were subjected to these two treatments.

The treated and untreated fruits were stored under simulated shipping conditions obtained in a reefer in which temperatures ranging from 50° F. to temperatures above room temperature were maintained.

Because of the difficulty in handling dry ice due to its sublimation characteristics resulting in pressure build-up in sealed containers, carbon dioxide gas was employed instead of dry ice. Carbon dioxide from a gas cylinder and air from a compressor were mixed and the mixture was led at atmospheric pressure into and out of a 9½-gallon pyrex glass jar in which the papayas were placed (Fig. 1). Proportionate quantities of gas and air were measured with flowmeters to obtain the required concentrations of carbon dioxide (5 to 65 percent). A control lot in normal air was also maintained.

Although the effect of differential flow rates for each concentration of carbon dioxide at various temperatures was not determined, all treatments were subjected to a constant flow rate of 250 ml. per minute as measured with flowmeters. Previous tests indicated that for each temperature employed, air at flow rates varying from 200 to 350 ml. per minute had similar effect on the ripening process of the papaya.

After a period of 5 or 6 days in modified atmosphere to simulate shipping time to the West Coast by surface transportation, the fruits were removed to room temperature conditions and examined daily for determination of quality and shelf life. In initial experiments, the effect of carbon dioxide storage on the quality of fruits up to the edible ripe stage was determined. Quality was based on degree of incidence of storage decay, aroma, flavor, and internal and external color development. In subsequent

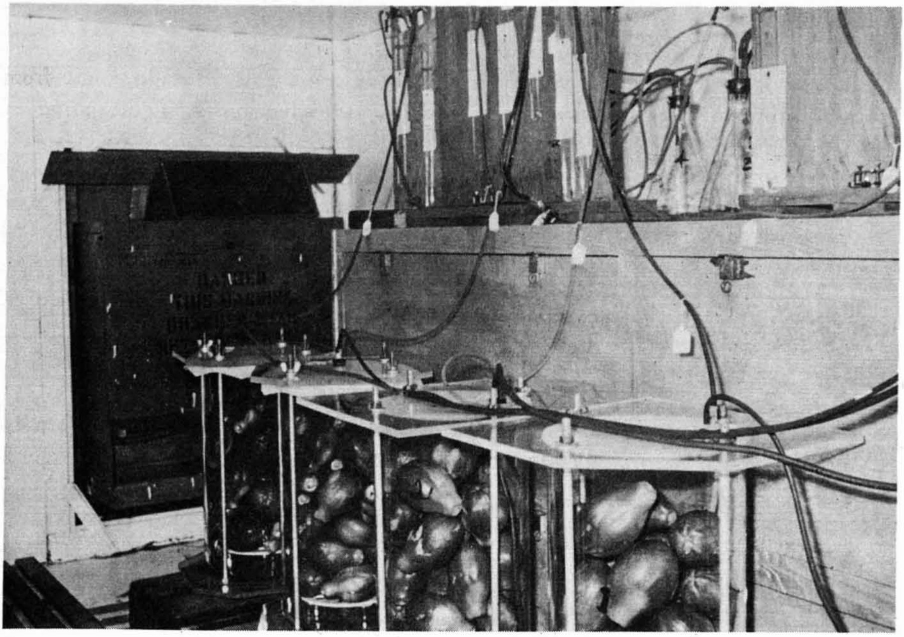

FIGURE 1. Papayas stored in constant carbon dioxide concentrations regulated by flowmeters.

experiments, the effect of the storage treatments on the shelf life was studied. Shelf life was based on the maintenance of marketable life as determined by the absence of decay and degree of ripeness.

RESULTS

Quality at 50° F.

Initial experiments indicated that untreated papayas could tolerate storage in carbon dioxide concentrations of 5 to 30 percent at 50° F. Higher concentrations were detrimental in that the internal color, aroma, and flavor were adversely affected. In general, up to the edible ripe stage, the lower levels of the gas had no effect on the incidence of storage decay. However, higher levels indicated some control.

The effect of carbon dioxide storage on fumigated papayas is shown in the data presented in Table 1. As in the case of untreated papayas the upper limit of carbon dioxide concentration for tolerance by the fruits was 30 percent. In contrast to untreated fruits, 30 percent CO_2 tended to reduce the storage decay incidence of fumigated fruits, whereas the higher concentrations produced no effect. The higher concentrations also delayed external color development (Table1).

TABLE 1. Effect of carbon dioxide storage at 50° F. on the quality of color turning to ½-colored ethylene dibromide-fumigated papayas

Percent CO_2 (storage)*	Edible ripe stage				
	Decay percentage	External color	Internal color	Aroma	Flavor
10	90.9	Normal	Normal	Normal	Normal
20	78.9	Normal	Normal	Normal	Normal
30	69.7	Normal	Normal	Normal	Normal
40	90.9	Delayed 1 day	Normal to off	Reduced to off	Off
50	81.8	Delayed 2 days	Normal to off	None to off	Off
60	84.8	Delayed 3 days	Normal to off	None to off	Off
Air	84.8	Normal	Normal	Normal	Normal

*Thirty-three fruits per treatment.

In further tests the effectiveness of the hot water treatment in the control of storage decay was demonstrated with fumigated and unfumigated fruits stored in air and in 30 percent CO_2.

Quality at 55° F.

Experiments conducted at 55° F. indicated that, in general, as in the case of fruits stored at 50° F., the tolerance limit of both fumigated and unfumigated papayas to carbon dioxide is a concentration of 30 percent. In general, carbon dioxide storage was ineffective in controlling storage decay in both fumigated and unfumigated fruits at 55° F.

The control of storage decay by the hot water treatment in fumigated fruits stored in both air and carbon dioxide is readily discernible in Table 2. It was demonstrated that this control is evident even for fruits stored in carbon dioxide concentration (35 percent) which is detrimental to the quality of the fruit. The 35 percent CO_2 storage also delayed the external color development (Table 2).

TABLE 2. Effect of carbon dioxide storage at 55° F. on the quality of color turning to ¾-colored hot water-treated and ethylene dibromide (EDB)-fumigated papayas

Treatment*	Edible ripe stage				
	Decay percentage	External color	Internal color	Aroma	Flavor
EDB, air	72.7	Normal	Normal	Normal	Normal
EDB, 35% CO_2	63.6	Delayed 2 days	Normal to off	Reduced to off	Normal to off
Hot water, EDB, air	9.1	Advanced slightly	Normal	Normal	Normal
Hot water, EDB, 35% CO_2	22.7	Delayed 1 day	Normal to off	Normal to off	Normal to off

*Twenty-two fruits per treatment.

Quality at Higher Temperatures

Untreated papayas were stored in 10 to 60 percent CO_2 at 76°–83° F., 83°–88° F., and 86°–89° F. At all of these temperatures, in general, papayas tolerated up to 30 percent CO_2, and 10 percent CO_2 afforded the most protection against storage decay. The data of Table 3 obtained from fruits stored at 76°–83° F. are typical of the results from the higher temperature experiments.

Shelf Life

The control of storage decay is the most important factor determining shelf life of normal papayas. The previous experiments indicated that a concentration of carbon dioxide of approximately 10 percent in the storage medium at temperatures above 55° F. was effective in controlling decay of fruits up to the edible ripe stage. Consequently in the following experiments, fumigated papayas were subjected to carbon dioxide concentrations varying from 5 to 15 percent at high temperatures in the initial storage period followed by storage at room temperature conditions. Shelf life of the fruits, as determined by the extent of decayed and overripe fruits, was observed daily after removal to room temperature. Because the prevalence of decay is more important than overripeness in the determination of marketability, overripe decayed fruits were considered as "decayed" only in the compiled data.

TABLE 3. Effect of carbon dioxide storage at 76°–83° F. on the quality of color turning to ¼-colored untreated papayas

Percent CO_2 (storage)*	Edible ripe stage				
	Decay percentage	External color	Internal color	Aroma	Flavor
10	31.2	Advanced slighty	Normal	Normal	Normal
20	78.1	Normal	Normal	Normal	Normal
30	46.9	Normal	Normal	Reduced slightly	Normal
40	96.9	Normal	Normal	Reduced	Normal
50	100.0	Normal	Normal	Reduced	Normal
60	100.0	Normal	Normal	Reduced	Normal
Air	93.8	Normal	Normal	Normal	Normal

*Thirty-two fruits per treatment.

Examination of fruits immediately after removal from initial simulated shipping storage at 65° F. showed that the decay percentage in the 10 percent CO_2 storage was only half of that in the air (Table 4). However, at room temperature, fruits which had been subjected to carbon dioxide decayed so rapidly that after one day the percentage of unmarketable fruits was nearly as high as that of air storage. After another day at room temperature over 90 percent of the fruits in all treatments were unmarketable. At the end of the third day all fruits were unsalable, the overripe fruits contributing only a small part to the number of unmarketable fruits in all cases. At 65° F., even 5 and 10 percent CO_2 delayed color development (Table 4).

Similar results were obtained with fruits initially stored at 78°–84° F. and 87°–91° F. However, at these temperatures, the shelf life was correspondingly shorter than at 65° F., i.e., fruits stored at 78°–84° F. and 87°–91° F. were all unmarketable two days and one day, respectively, after removal to room temperature, whereas those stored at 65° F. were all unmarketable in three days (Table 4).

TABLE 4. Effect of carbon dioxide storage at 65° F. on the shelf life of color turning to 1/3-colored ethylene dibromide-fumigated papayas

Storage*	After 6 days at 65° F.			In open at room temperature									External color‡
				1 day			2 days			3 days			
	Decay (%)	Over-ripe† (%)	Total un-marketable (%)	Decay (%)	Over-ripe† (%)	Total un-marketable (%)	Decay (%)	Over-ripe† (%)	Total un-marketable (%)	Decay (%)	Over-ripe† (%)	Total un-marketable (%)	
Air	23.5	0.0	23.5	47.0	0.0	47.0	91.2	5.9	97.1	94.1	5.9	100.0	
5% CO_2	17.6	0.0	17.6	52.9	0.0	52.9	94.1	5.9	100.0				Delayed 1 day
10% CO_2	11.8	0.0	11.8	41.2	0.0	41.2	85.3	5.9	91.2	94.1	5.9	100.0	Delayed 2 days
15% CO_2	26.5	0.0	26.5	55.9	0.0	55.9	94.1	2.9	97.0	97.1	2.9	100.0	No delay

* Thirty-four fruits per treatment.

† Overripe decayed fruits are classed under "decay" only.

‡ As compared with air storage.

Carbon Dioxide vs. Hot Water on Shelf Life

As shown by the experiments reported above, beneficial effects of carbon dioxide storage are obtained only at temperatures above those optimum for storage. Carbon dioxide storage of papaya would therefore be useful only if its beneficial effects were sufficient to offset the effects of higher than optimal storage temperature. To test this possibility, a final experiment was conducted to compare the relative beneficial effects of carbon dioxide with those of the hot water treatment.

One lot of fumigated papayas was stored in 10 percent CO_2 at 65° F., and another lot was hot water-dipped, fumigated, and then stored in air at 55° F. A corresponding control lot in air was also maintained for each temperature. The results are recorded in Table 5.

In air storage, fruits stored at 55° F. retained their marketability better than those stored at 65° F., the latter becoming totally or nearly totally unmarketable in three and two days, respectively, at room temperature due to decay (Table 5). At 65° F., the marketable life of the fruits stored in 10 percent CO_2 was slightly better than that of the fruits in air. However, fruits stored in air at 55° F. had less decay than those stored in 10 percent CO_2 at 65° F.

The beneficial effect of the hot water treatment is evident from the data in Table 5. Whereas, at the end of the third day of storage at room temperature all or nearly all of the fruits in the other treatments were decayed, only approximately one-fourth of the hot water-treated fruits were decayed. Generally, depending on initial stage of ripeness, about two or three days at room temperature are required subsequent to 55° F. storage for six days, for fruits to be edible ripe. Thus, the control of decay brought about by the hot water treatment up to this point is very significant. Subsequent delay in the development of the decay for several more days in storage is also important.

In general, concomittant with the extension of shelf life is the delay in color development (Table 5). However, in spite of the same degree of delay in color development in the hot water-treated and untreated fruits stored at 55° F., the shelf life was greater in the treated than in the untreated lot. This is a manifestation of the control of decay by the hot water.

TABLE 5. Effect of storage media on the shelf life of color turning to 1/3-colored ethylene dibromide-fumigated papayas

Storage*	After 6 days in initial storage			In open at room temperature								
				1 day			2 days			3 days		
	Decay (%)	Over-ripe† (%)	Total un-marketable (%)	Decay (%)	Over-ripe† (%)	Total un-marketable (%)	Decay (%)	Over-ripe† (%)	Total un-marketable (%)	Decay (%)	Over-ripe† (%)	Total un-marketable (%)
10% CO_2, 65° F.	13.3	0.0	13.3	60.0	0.0	60.0	83.3	3.3	86.6	96.7	3.3	100.0
Air, 65° F.	46.7	0.0	46.7	80.0	0.0	80.0	100.0	0.0	100.0			
Hot water, Air, 55° F.	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	10.0	26.7	3.3	30.0
Air, 55° F.	0.0	0.0	0.0	26.7	0.0	26.7	66.7	0.0	66.7	96.7	0.0	96.7

* Thirty fruits per treatment.

† Overripe decayed fruits are classed under "decay" only.

TABLE 5. Continued

Storage*	In open at room temperature												External color‡
	4 days			5 days			6 days			7 days			
	Decay (%)	Over-ripe† (%)	Total unmarketable (%)	Decay (%)	Over-ripe† (%)	Total unmarketable (%)	Decay (%)	Over-ripe† (%)	Total unmarketable (%)	Decay (%)	Over-ripe† (%)	Total unmarketable (%)	
10% CO_2, 65° F.													Delayed 2 days
Air, 65° F.													
Hot water, Air, 55° F.	43.3	13.3	56.6	56.7	20.0	76.7	63.3	23.3	86.6	63.3	36.7	100.0	Delayed 5 days
Air, 55° F.	100.0	0.0	100.0										Delayed 5 days

* Thirty fruits per treatment.
† Overripe decayed fruits are classed under "decay" only.
‡ As compared with storage in air at 65° F.

DISCUSSION AND CONCLUSION

In general, fumigated papayas do not tolerate concentrations of carbon dioxide greater than 30 percent in modified atmosphere storage at temperature levels used in these studies. Concentrations of the gas above this impair the quality of the fruit.

At 50° and 55° F., in general, there is little or no control of decay by carbon dioxide. However, at temperatures of 65° to 91° F., 10 percent CO_2 has an effect in reducing the decay up to the edible ripe stage of the fruit. Storage at room temperature after the simulated shipping storage causes the fruits to decay very rapidly. This indicates the lack of residual effect of the gas which is reported to be present in certain commodities treated with this gas *(10)*.

In the present studies, there is no evidence of carbon dioxide supplementing standard refrigeration as reported for other fruits and vegetables *(5, 7, 11, 12, 16, 17, 18, 19)*, i.e. the gas does not reduce the temperature requirement for storage of papayas. The shelf life of fruits stored in 10 percent CO_2 at 65° F. was inferior to that of fruits stored in air at 55° F. (Table 5).

Hot water treatment followed by storage in air is far superior to carbon dioxide storage in maintaining the shelf life of the papayas. In spite of the initial advantage of the 10 percent CO_2 at 65° F. in controlling decay in storage, fruits treated with the recommended hot water treatment followed by storage at 55° F. in air *(1, 2, 6)* maintained their shelf life much longer than those stored in carbon dioxide. The gradual development of decay in hot water-treated fruits with storage at room temperature is an indication that the decay organisms are probably suppressed in their development by the applied heat until the fruits begin to break down (overripe).

It is concluded that the use of carbon dioxide affords no advantage in the storage of papayas. Consequently, the use of dry ice in the shipment of fresh fruits to the mainland U.S. from Hawaii is not considered to be feasible.

SUMMARY

1. The effect of carbon dioxide on the quality and shelf life of fresh papayas stored at simulated shipping conditions was determined.
2. At storage temperatures of 65°–91° F., 10 percent CO_2 checks the development of decay during the storage period only.
3. There is no residual effect of the gas since removal of the fruits from the gas medium causes immediate decay.
4. Hot water is superior to carbon dioxide in the control of storage decay.
5. The use of dry ice in the shipment of papayas is not feasible.

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